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THE ELECTRON ECHO 6 MECHANICAL DEPLOYMENT SYSTEMS

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ABSTRACT

The Echo 6 sounding rocket payload was flown on a Terrier boosted Black Brant vehicle on March 30, 1983. The experiment requirements resulted in the new design of a rocket propelled Throw Away Detector System (TADS) with onboard Doppler radar, a free-flyer forward experiment designated the Plasma Diagnostic Package (PDP), and numerous other basic systems. The design, developmental testing, and flight preparations of the payload and the mechanical deployment systems are described.

INTRODUCTION

The Electron Echo 6 program, a joint effort of the University of Minnesota School of Physics and Astronomy with the Sounding Rocket Division of Goddard Space Flight Center, is the sixth in a series of active magnetospheric research payloads. Echo 6 was launched from the Poker Flat Research Range, Fairbanks, Alaska, with a north-northeastward trajectory across auroral arcs. It included two onboard electron accelerators which injected electron beams of up to 40 KeV in energy and 0.25 amperes current as probes into the Earth's magnetosphere. The basic objective of the Echo series is to inject electrons so that they are magnetically guided along field lines to the conjugate point in the southern hemisphere, where they are reflected back to the region near their origin either by magnetic mirroring or by backscattering off of the atmosphere. Analysis of the detected echoes provides valuable information about the structure of the distant magnetosphere and the mapping of its electric field into the ionosphere. In the previous missions (Echo 1, 3, and 4) the echoing electrons have been detected by the beam-emitting payload when their two motions were matched. The evolution of the Echo program has resulted in the development of a multiple remote Throw Away Detector System (TADS) that greatly increases the spatial coverage of the echo detection system and gives more flexibility to the rocket trajectory. The primary emphases of Echo 6 were echo detection using TADS and electric field analysis using a free-flyer forward experiment designated the Plasma Diagnostics Package (PDP).

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FLIGHT PLAN

The scientific launch criteria had three requirements that: the magnetosphere be in an inflated tail like configuration, the local electric field be northward corresponding to an eastward electrojet, and the aurora be in the form of an intermediate intensity arc under the trajectory. The payload launch criteria required that there be no Sun on the payload at apogee, that all payload and ground systems be operational, and that the meteorological conditions be suitable. Because of the short-lived nature of the scientific event, the brevity of the flight, the complexity of the payload, the requirement for the precise placement of the TADs in space, and the necessity of accurate injection of the electrons relative to the magnetic field lines; a rigorous and detailed sequence of payload events was required for the flight plan. (See Figure 1). A series of complex Attitude Control System (ACS) maneuvers had to be coordinated to achieve these requirements. The synchronization of the onboard payload events was controlled by use of six mechanical timers and two electronic programmers. These events are detailed in the time-event sequence of Table 1.

Table 1: Echo 6 Time-Event Sequence

Time Sec	Alt Km	Event Description
-90	0	Systems to internal power
0	0	Terrier ignition, aerodynamic spin-up by fin offset
4	1	Terrier burnout
12	4	Black Brant ignition
44	37	Black Brant burnout, payload rotation at 3.6 rps
60	64	TAD section door ejection
62	68	ACS arm
64	71	Yo-Yo despin to 0.6 rps
66	76	Black Brant Motor separation (250 Kft)
66	76	ACS starts maneuvers to reference orientation
70	82	Nose cone ejection 5 mps relative velocity
80	100	PDP electric field booms unfold and lock
82	102	Detector high voltage enable on PDP and Main section
84	106	PDP deployment, 1.5 mps relative velocity
88	112	ACS despin to zero rps
93	118	ACS alignment to TAD deployment orientation
130	164	TAD spin-ups on and Doppler radars on
140	174	TAD 3 deployment, 10 mps relative velocity
143	177	TAD 1 deployment, 10 mps relative velocity
146	180	TAD 4 deployment, 20 mps relative velocity
149	183	TAD 2 deployment, 20 mps relative velocity
151	184	Electron accelerator system start
155	188	TAD spin-ups off and Doppler radars off
160	190	Electron accelerators on (first pulse)
244	216	Apogee
432	80	ACS off
538	6	Recovery system deployment (20 Kft)

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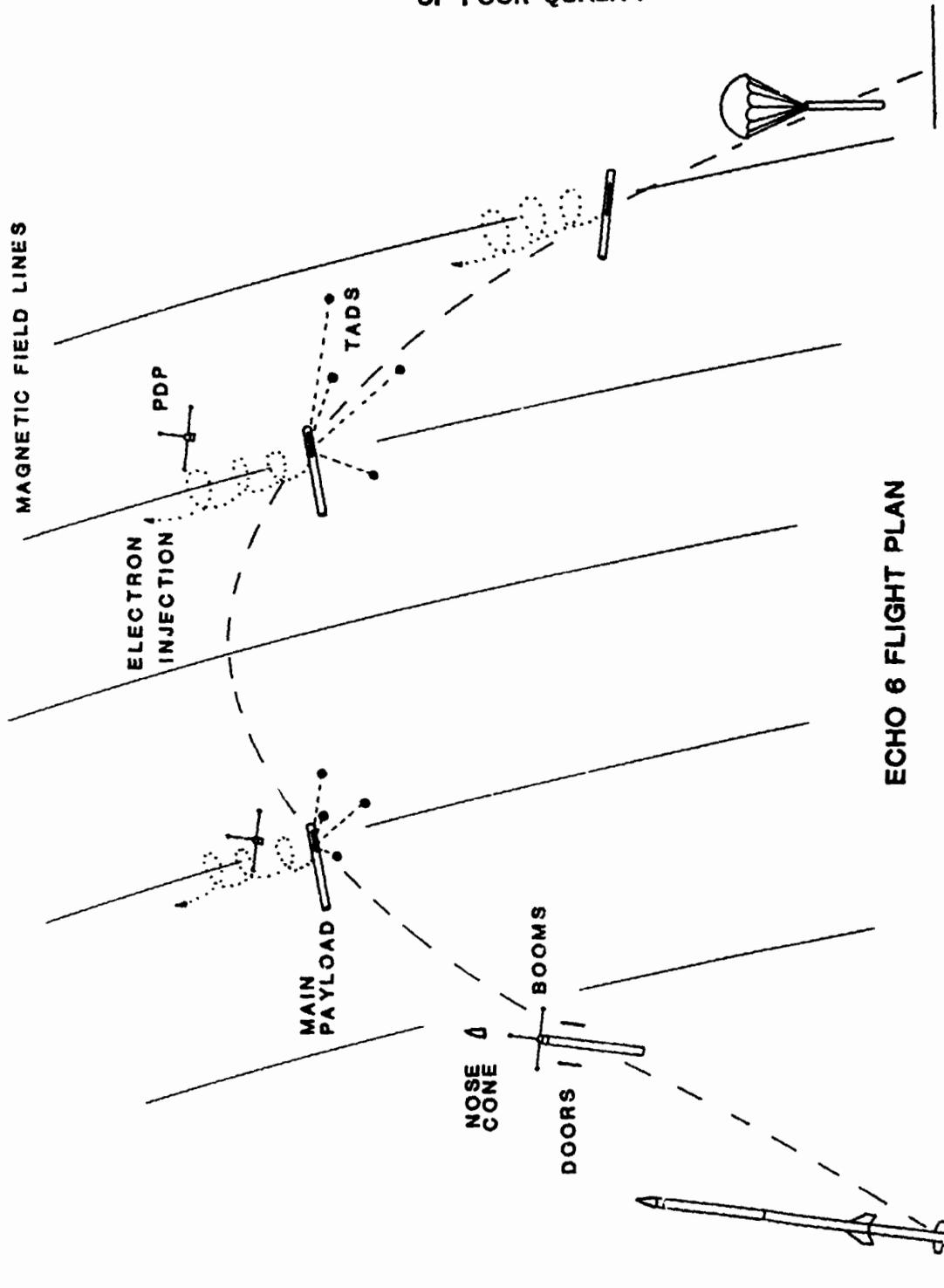


Figure 1. Echo 6 Flight Plan

THE PAYLOAD

Although the TADS was mechanically the most complex aspect of the Echo 6 payload, it was only one of several sophisticated systems that had to function for a successful mission. An index of the mechanical complexity of the entire payload is that 28 electro-explosive devices (squibs) were fired, some simultaneously and some sequentially, to separate the payload into 35 distinct pieces during the flight. To get an overview of this payload, refer to Figure 2 and Figure 3 beginning at the nose and working aft.

The one piece nose cone, which was 1.50-m (60-inches) long with a 3:1 ogive, was retained by a two piece V-band clamp at its base. Two squib actuated bolt cutters were used to sever the band screws, either of which would release the band. An ejection spring, in the tip of the nose cone, pushed off against the top of the payload when the band was cut. (This action is typical of all the payload separation bands.) Ejecting the cone exposed detectors and the electric field booms of the Plasma Diagnostic Package (PDP). The booms were spin deployed when a cable cutter was actuated. The PDP in turn was released by a V-band and was spring ejected forward to expose the electron accelerators and detectors on the forward portion of the main payload. Aft was the electron accelerator battery can containing 220 kg of high-voltage batteries. Further along was the Throw Away Detector section with spin-deployed doors and rocket-propelled TADs.

Aft of the TAD section came the nearly standard sections used on most sounding rocket flights. The telemetry (TM) section supplied both 28-volt power and timing signals to the payload as well as telemetering the data back to the ground. The ACS stabilized and pointed the TADs and electron accelerators. Following was the recovery section which deployed a parachute to decelerate the main payload. Finally, there was the igniter housing which ignited the Black Brant sustainer, despun the whole rocket with yo-yo's to 0.6 rps, and separated the sustainer from the payload. Below the sustainer was the Terrier booster.

The total payload weight was 2310 kg (1050 lbs), of which 2134 kg (970 lbs) reached a burnout velocity of 2020 mps and an apogee altitude of 216 km. The payload, which was 6.5-m (254-inches) long and 0.44 m (17.26 inches) in diameter, sat on top of a 9.8-m (385-inches) long sustainer and booster.

PLASMA DIAGNOSTIC PACKAGE (PDP)

The design of the PDP section of the payload was dictated by the requirement of stowing electric field booms under the nose cone and the need to provide a ground plane for an S-band antenna. (See Figure 4). The core of the section was a 0.61-m (24-inch) long can of which only the top quarter of its volume was used for housing the PDP telemetry system and batteries. To simplify spin balance of the PDP the battery packs were located symmetrically. A set of doors was placed on opposite sides of this section for easy access to the batteries. The remaining empty volume of the can acted as a cover for the forward portion of the main payload containing detectors and the electron accelerator turret. The S-band antenna was located in the middle of the section to provide adequate ground planes on each side. The experiment portion of the PDP mounted to the front of the PDP can and was exposed by the

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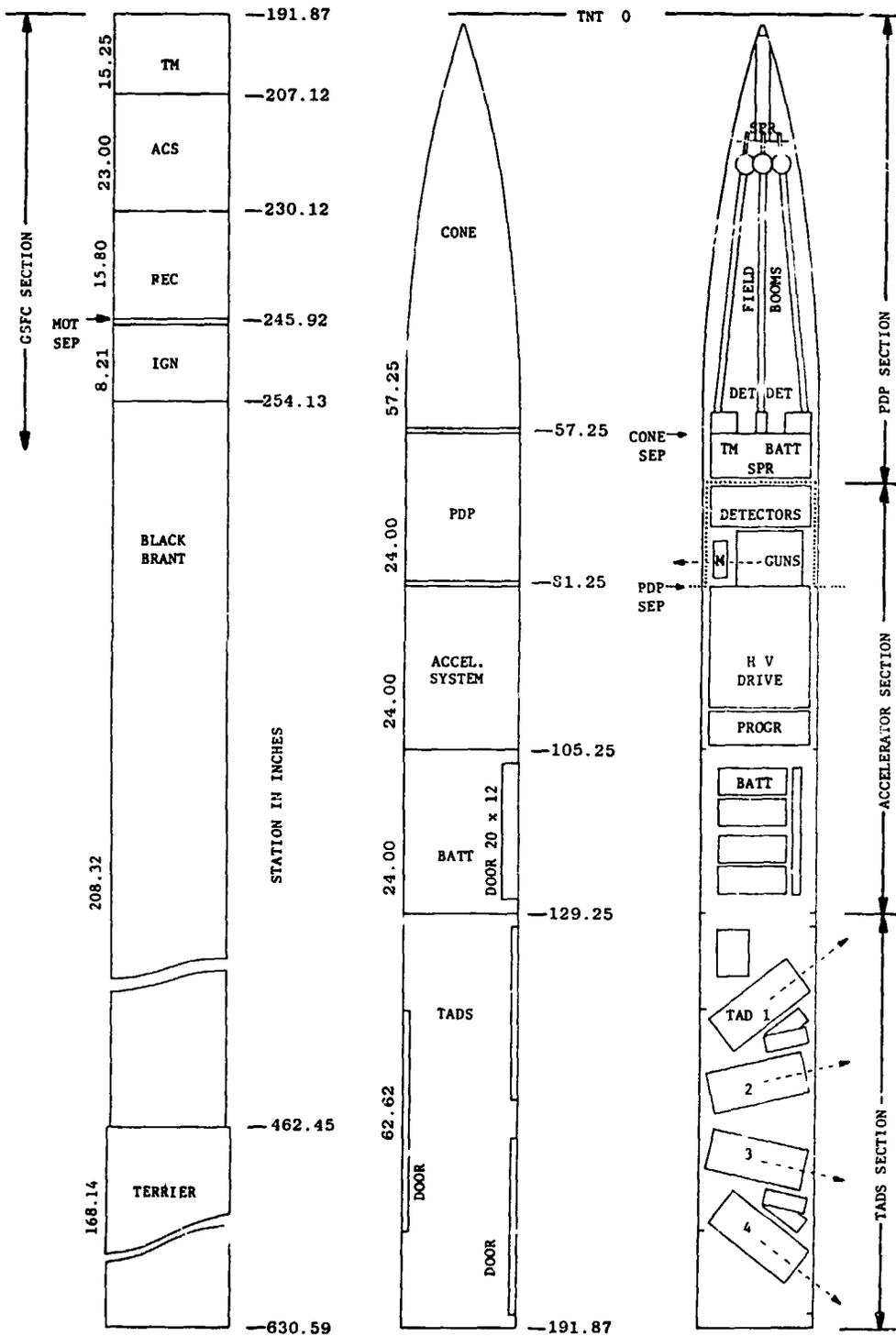


Figure 2. Echo 6 Payload-Vehicle Layout

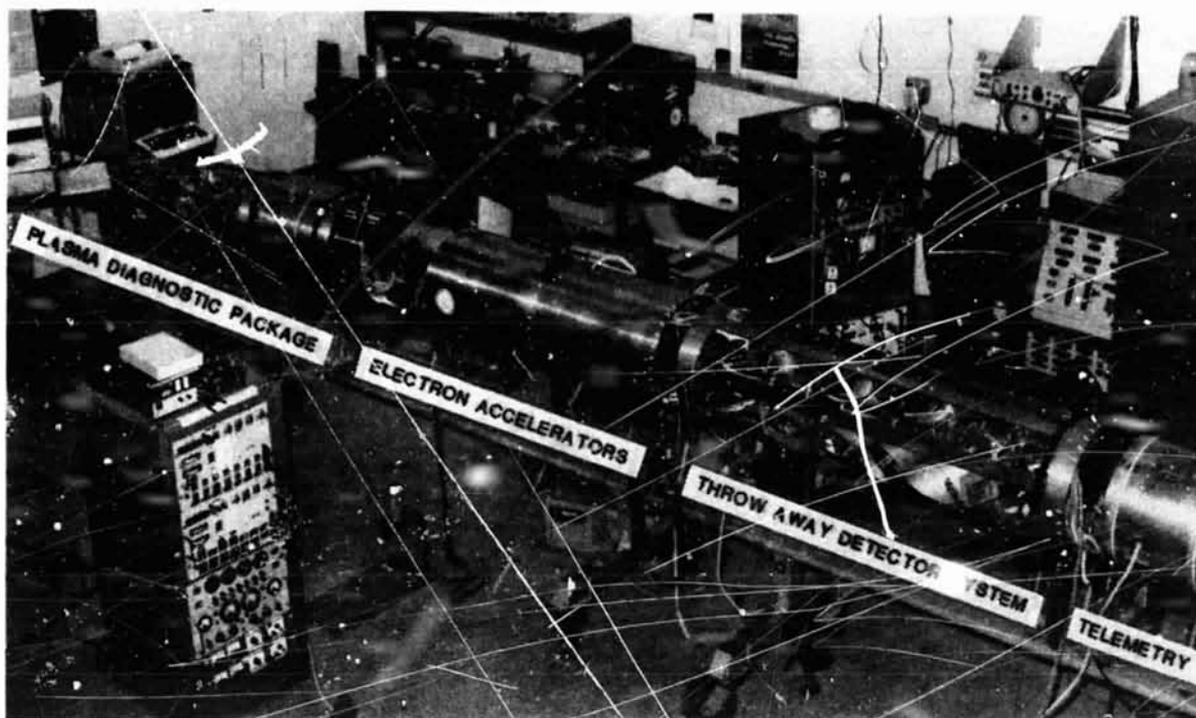


Figure 3. Echo 6 All-Up Payload (During GSFC Integration)



Figure 4. Echo 6 PDP Flight Configuration (During GSFC Mass Properties)

forward spring ejection of the nose cone. Following the deployment of the nose cone, two sets of orthogonal electric field probes were released from their forward stowed position by the squib action cutting of a cable while the payload was still spinning at 0.6 rps. The four probes were dependent on the centrifugal forces present to torque them 90° into their locked positions perpendicular to the PDP-main payload spin axis. The probes then telescopically and centrifugally extended to almost twice their stored length, separating each pair of conducting spheres on an axis by 3.63 meters. A spring loaded fifth probe was also released and rotated by a torsion spring 180° from its aft pointing stowed position to its locked forward position along the spin axis.

The ejection of the PDP from the main payload was accomplished by a single spring axially located to minimize tip-off at separation. With the 470 lb spring, the PDP achieved a 1.5 mps velocity relative to the main payload. This velocity was measured by a system consisting of a multiturn potentiometer mounted on the main payload and wound with a cord attached to the PDP body.

The ejection spring was designed as a cartridge that could be compressed externally with a loading screw. Once the cartridge was loaded, safety screws were installed and the loading screw removed. This mounting allowed the safety screws to remain in place until just before flight. Access to the safety screws and the velocity pot was through the battery access doors.

Of particular concern was the fact that during ejection relative rotation between the PDP can and the enclosed accelerator turret would destroy the PDP antenna connector that protruded radially inward. A set of rails was added to guide the separation and an antitorque shoe was provided to prevent rotation.

THROW AWAY DETECTOR SYSTEM (TADS)

In previous GSFC programs TADs were deployed by a combination of springs and the centrifugal force created by the spinning rocket payload, resulting in a random dispersion of the TADs away from the main payload. Echo 6 required that the TADs achieve separations of several kilometers from the main payload in a predetermined pattern. Not only was centrifugal deployment too imprecise, but the energy requirements of ejecting four 6 kg TADs at 10 to 20 mps were too high for the safe use of springs. After considering various alternative means of deployment, a rocket propelled, spin stabilized TADs was developed.

The resulting design of the TAD consisted of a cylindrical aluminum tube 0.33-m (13-in) long and 0.14 m (5.5 in) in diameter (Figure 5) containing three solid-state electron detectors, an electrostatic analyzer, a 3-axis aspect magnetometer, power supply, NiCad-battery pack, 50 KHz data encoder, transmitter, S-band antenna, and a small solid fueled rocket motor for propulsion. In essence each TAD was a complete rocket experiment with its own detectors, data system, and means of propulsion.

The TAD propulsion motors were acquired as overaged spin motors from the NASA Delta Program. The motors came in two versions (0.3KS40 and 0.6KS40) both with 28 newtons (40 lbs) of thrust but differing burn times of 0.3 and 0.6 seconds. The two versions provided the capability of propelling the 6 kg (13 lb) TADs to the approximate velocities of 10 and 20 meters

TAD SECTIONAL VIEW

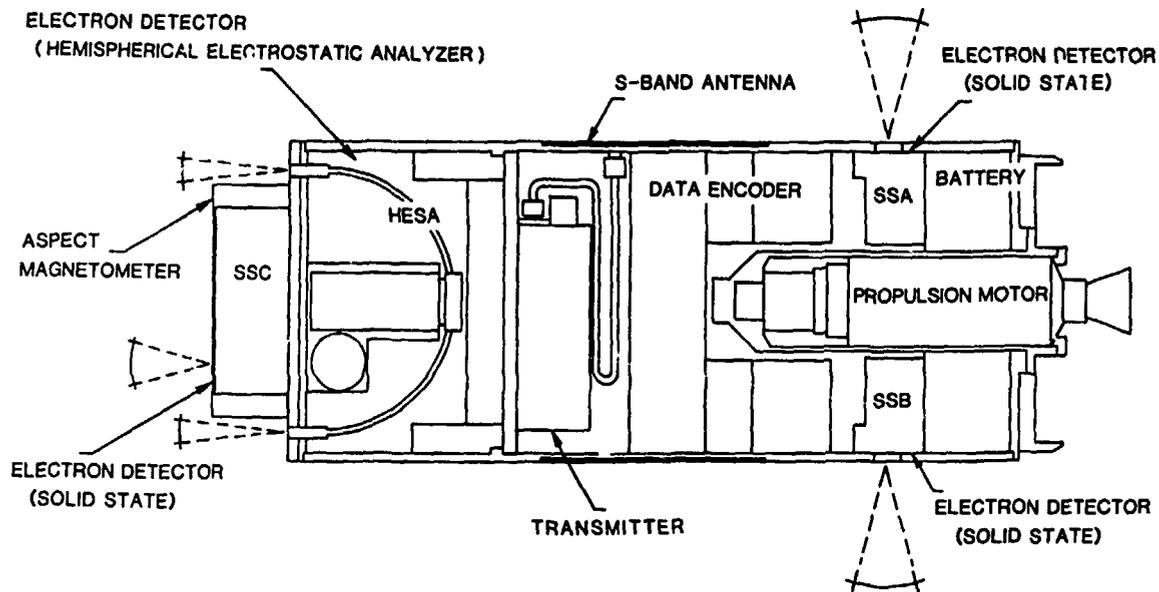


Figure 5. Echo 6 TAD Sectional View

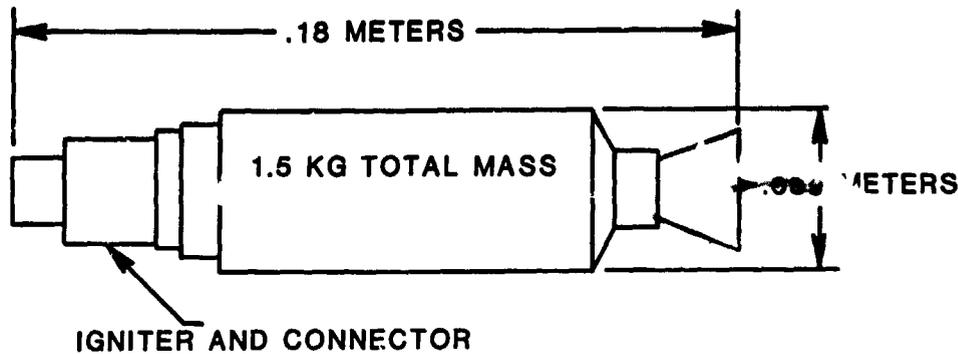
per second. The motors were 0.18-m long and 0.039 m in diameter with an igniter and connector on one end and a small exhaust nozzle on the other (Figure 6). Each motor had a mass of approximately 1.5 kilograms. A test firing of a flight type rocket motor was made at the GSFC propulsion test site, with some exhaust products being noted on the anchoring weights. Concern for the effect that the exhaust plume might have on the payload and undeployed TADs at flight altitude prompted further consideration.

The TAD S-band antennas were adapted from a design used for 0.13 m (5 inch) military projectiles. The antennas were installed as a band around the perimeter of the cylindrical TADs staying within a recess inside the TAD 0.14-m (5.5-inch) diameter thus allowing the TADs to slide smoothly in their launch tubes. The miniature S-band antennas were tested at GSFC to determine their radiation patterns and effectiveness.

To ensure that the TADs remained stable throughout their 300-second flight they were individually spin balanced at GSFC and then spun up in flight to approximately 8 rps prior to their deployment. Spinning reduced the effects of motor burn asymmetry, and balancing to a static limit of 2.0 ounce-inches and a dynamic limit of 5.0 ounce-inches squared kept their coning half angles to within 0.5°.

To spin-up the TADs, launch tubes were contained in the payload by a spool housing supporting two 0.15 m (6 inch) inner diameter sealed ball bearing raceways (Figures 7 and 8). This allowed both the launch tubes and the TADs latched within them to be spun by driving the launch tubes with timing belts connected to vacuum application electric dc motors.

TAD PROPULSION MOTOR



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MARC 4C4
0.3-KS-40 AND 0.6-KS-40

Figure 6. Echo 6 TAD Propulsion Motor

On the rear of each spinning launch tube was a latching mechanism that retained each TAD until a bellows actuator was fired by a timing pulse. The bellows actuators not only unlatched the TADs but also activated micro switches that removed safety shorts from the rocket motor igniter leads. This action applied the power which was formerly applied to the actuator across the igniter leads. This technique produced a near simultaneous release of the TADs and ignition of their rocket motors. There were also safety shorting plugs on the rear of each launch tube which shorted out both the bellows actuators and rocket motors during integration.

To interface the functions of the TAD including turnon, checkout, and firing; a 10-band copper slipring with a redundant set of copper-graphite pick up brushes was mounted to the rear of each launch tube. This arrangement included a spring clip socket which the TAD contacted when latched in the launch tube. The flight turnon of the TADs was made through two redundant micro switches that were held off by the walls of the launch tubes. When the TADs exited the tubes these switches enabled the TADs to internal power.

K-band Doppler radar units were used for measuring the TAD velocities after deployment and ultimately their relative displacement as a function of time. The units, operating at 24.15 GHz, were directed at points along the TAD trajectories where the propulsion motors burned out to minimize the reflected noise created by the ionized exhaust. The beat signals resulting from the mixing of the incident radiation and the Doppler shifted reflected signals were tracked by phase lock loop circuits and recorded by TM counters. To increase the effective TAD radar cross section small copper corner reflectors were affixed to the aft end of the TADs.



Figure 7. Echo 6 Spin-Up Assemblies with TAD

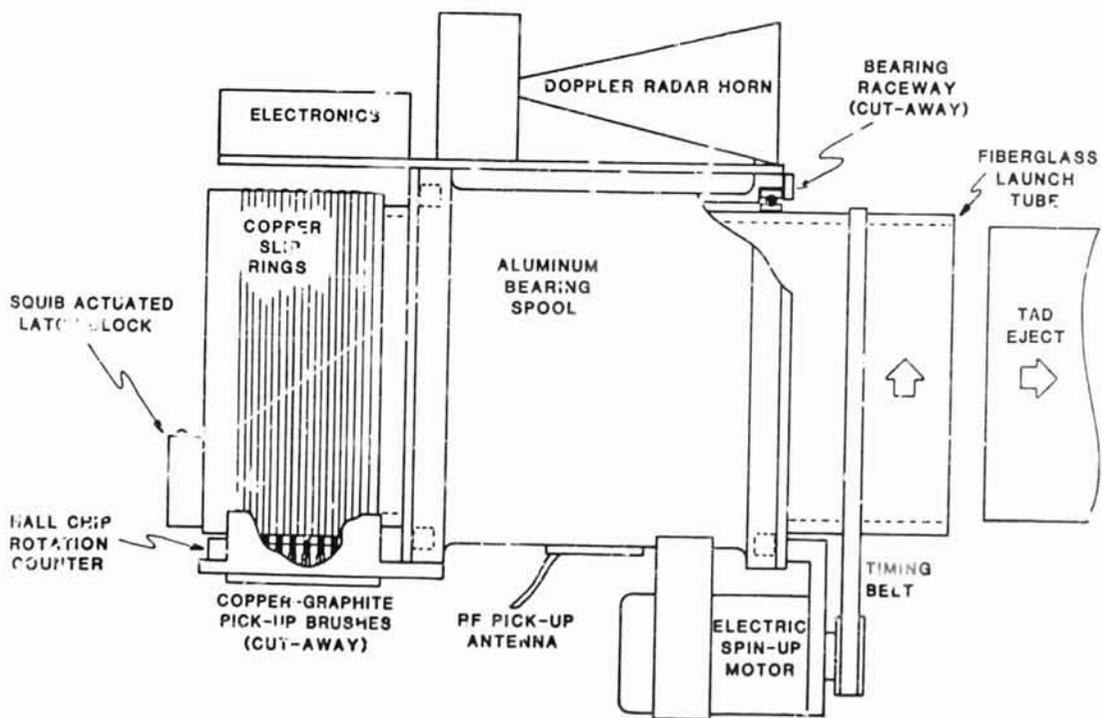


Figure 8. Echo 6 Spin-Up Assembly Sectional View

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Because each TAD has its own telemetry system complete with transmitter and antenna, it was necessary while on the launch pad to energize them and run signal checks while in the launch tubes. The radiation checks were accomplished by making the launch tube out of RF transparent fiberglass. To get the signal out of the rocket skin, a small pick-up antenna was positioned outside of the rotating fiberglass launch tube and the signal transferred through a length of coax cable to some RF BNC pullaways on the skin. This was, in effect, an RF slipring passing the signal to an external "cheater" antenna near the launch pad.

In the flight configuration four spin-up units with TADs were housed in the TAD section (Figures 9 and 10). This section consists of two ringed bulkheads connected by six longerons. Across two sets of these longerons were lightened plates to which the TAD spin-up units mounted. This construction was used because of the need for large openings on two opposite sides of the section. The front opening was to allow the TADs to exit and the other was used to vent the rocket exhaust and allow access for arming the motors before flight.

These openings were covered by doors held in place by a series of latch blocks on both sides bolted to latch bars. These blocks engage hooks on either side of the door. If either latch bar is pulled, the hooks release on that side and the door rolls off about the other side. If both sides were released simultaneously, the door simply moved out radially causing either a leading edge, a trailing edge, or a simultaneous release to occur. The latch bars were pulled by Horex 2900 linear actuators. The rest of the skin of the section which was not devoted to doors had removable panels to allow access to wiring and the latch system.

TEST PROGRAM

One of the first developmental tests of the TAD system was to establish the feasibility of using police radar units for the Doppler measurement of TAD velocities. A dummy TAD was built and powered by a Flight Systems Inc. series F model rocket motor. This motor has thrust characteristics very similar to the Delta spin motors at 1/1000 the cost. The TAD was put on a horizontal guide wire and the motor ignited. The TAD slid down the wire at speeds even exceeding the desired 20 mps and the radar successfully monitored the velocity. For the first spinning ejection test of the TAD and spin unit the model rocket motor was called upon again, assisted by a tether line and counterbalance weight as the TAD was vertically deployed.

Arrangements were also made to test fire a dummy TAD from the spinning launch tube in the 18-meter sphere at the NASA Langley Research Center. The sphere was evacuated, the TAD spun up, the radar turned on, and the firing sequence initiated. Viewing by high-speed cameras showed the TAD travelling very near to its theoretically calculated velocity with no visible evidence of an exhaust plume. The TAD also landed square in the net rigged for it. When the sphere was vented, no evidence of exhaust products was found and the sheet metal exhaust shroud was eliminated.

The integration test and evaluation program consisted of flight vibration, mass properties measurement, and a series of spinning deployments for the main payload and PDP. To begin with, a series of door deployment tests

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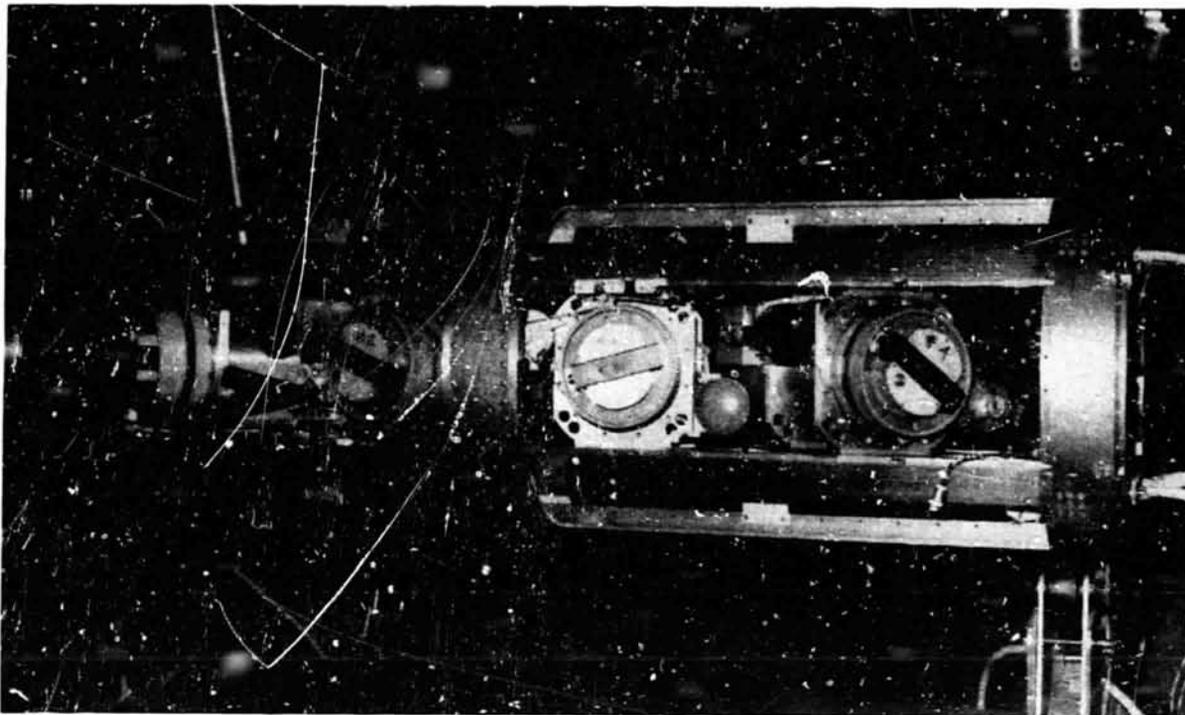


Figure 9. Echo 6 TAD Section Front View

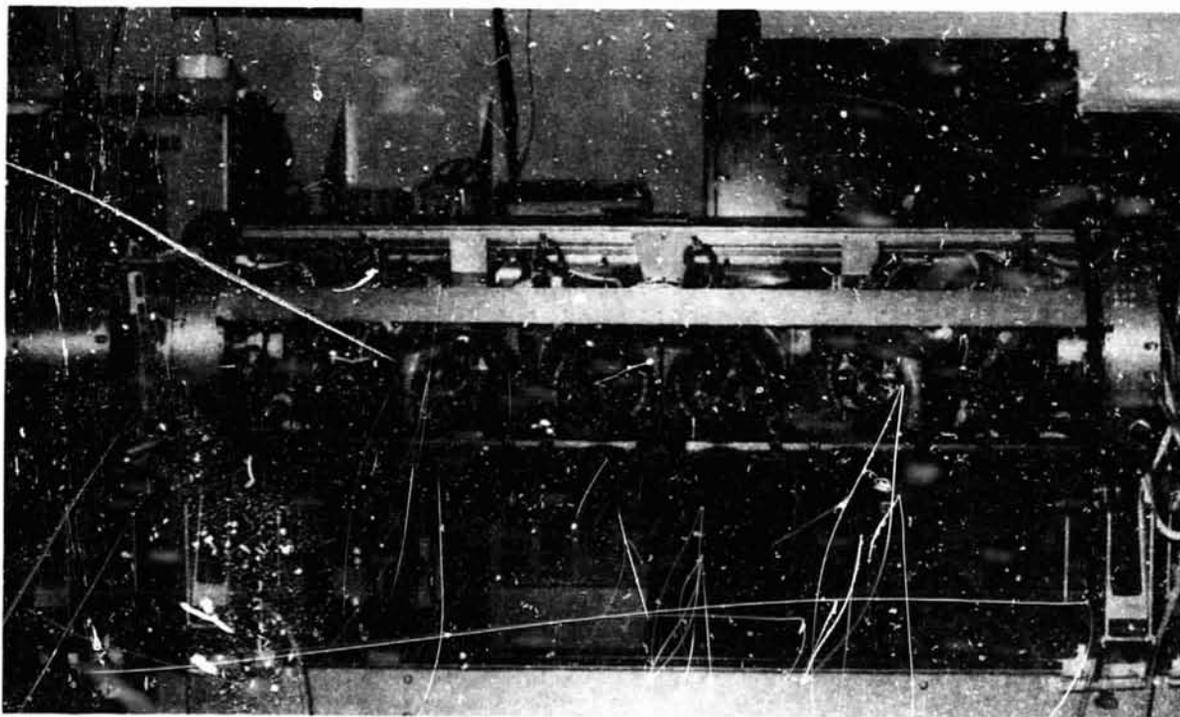


Figure 10. Echo 6 TAD Section Rear View

were conducted to verify the operation of the latch bar system and the three different modes of release. The payload was attached to a spin table and spun up to rates as high as 4 rps (maximum theoretical spin rate of vehicle), the squibs were fired, and the deployed doors were caught in a net. Closed circuit television was used to monitor the action.

The next series of tests were on the PDP. The first, boom deployment, was rather straight forward. The payload was spun up, the squibs fired, and the booms deployed on cue. Then came the spinning separation of the PDP from the accelerator section which was complicated by the requirement for zero gravity simulation. The usual test procedure is to use a counterweight to a line running over a pulley and down to the ejected payload. This method is not suitable for a spinning payload with several 'g's of acceleration. To solve the spin problem, a special low-friction swivel developed for a high altitude parachute was used. This swivel has some Belleville washers to unload the bearing under high loads. These washers spring out of the way under low loads to let the low-friction, light-duty bearing spin freely. This free spin was needed on the counterbalance line because of the necessity of avoiding any relative spin between the PDP and the accelerator section. The 2.5 'g' acceleration of the PDP was nullified by running the line through a 3:1 pulley arrangement and by using a counterbalance weight three times that of the PDP. A one-way block was used to snub the system. The deployment test itself, went smoothly. The nose cone had an initial acceleration of 13 'g's. To counteract this, during testing a length of surgical rubber bungee was added to the system to remove the slack from the line during the initial acceleration.

FIELD OPERATIONS AND LAUNCH

The 2 month long, detailed integration of the Echo 6 payload at GSFC culminated with the shipment of the payload and the travel of over 45 support personnel to the Alaska launch site. In February, all the Echo 6 equipment arrived at Poker Flat and the payload was prepared for launch. After the payload had been built up and the experiments given a checkout, the payload was taken to the motor preparation building and mated to the Black Brant sustainer. There the TAD rocket motors were installed with safety shorting plugs attached. The payload with sustainer was then taken to the launch site and combined with the Terrier booster that had been suspended on the launch rail earlier. After completing prelaunch checks, the payload was armed for flight by removing the safety plugs from the back of each TAD, removing all other safety screws and arming the 'g' timers. The deployable doors were reinstalled and secured. Subsequent to a series of delays caused by weather, electrical and mechanical problems, and some minor damage to the launch vehicle, Electron Echo 6 was launched at 06:59:51 on March 30, 1983 UT with the desired launch criteria and geophysical conditions being met.

CONCLUSION

The flight of Echo 6 was mechanically flawless, even in intimate detail. The vehicle propelled the payload to a near nominal trajectory with the predicted final roll rate. The ACS performed its maneuvers to better than its tolerance specifications. The PDP deployment was executed with the proper spin rate and separation velocity. The electric field booms were deployed perfectly. The TAD section doors were ejected, the TADs spun up, fired, and deployed with the Doppler radar measuring their velocities. The main payload

electron accelerator was started on time and injected electrons at the anticipated power according to the preset programmer. The scientific instrumentation on all the sections performed nominally with the six telemetry links from the main payload and free-flyers transmitting, being received, and recorded with excellent signal-to-noise characteristics. In summary, it may be said that the Echo 6 mission performed as anticipated and that the instrumentation made all of the measurements necessary for investigating the major scientific objectives.

This endeavor involved 10's of man years of effort and covered 1 month short of 3 years from inception to launch. The overwhelming success of the mission is a testimony to the extensive cooperation and dedication of the groups involved: NASA Headquarters, NASA/Goddard Space Flight Center, University of Minnesota, General Electric MATSCO, University of New Hampshire, NASA/Wallops Flight Facility, Poker Flat Research Range, University of Alaska, Physical Science Laboratory NMSU, Bristol Aerospace, and numerous other scientists, engineers, contractors, technicians, machinists, and suppliers.

The scientific data analysis is vigorously underway with many exciting results being investigated and reported.